Modeling and Measuring Fish Backscatter at Multiple Frequencies

John K. Horne[1]
Cooperative Institute for Limnology and Ecosystem Research, University of Michigan
NOAA Great Lakes Environmental Laboratory
[1]Current Address: University of Washington and Alaska Fisheries Science Center
7600 Sand Point Way N.E., Bldg. 4, Seattle, WA 98115-0070
phone: (206) 526-4618 fax: (206) 526-6723 e-mail: john.horne@noaa.gov

J. Michael Jech
Northeast Fisheries Science Center
166 Water St., Woods Hole, MA 02543
phone: (508) 495-2353 fax: (508) 495-2258 e-mail: michael.jech@noaa.gov
Award: N00014-98-1-0148

LONG-TERM GOAL

The long-term goal of this program is to quantify, understand and predict acoustic backscatter from fish.

OBJECTIVES

Objectives of this project include: quantifying the relative importance of biological and physical factors that influence variability in backscatter amplitudes; comparing backscatter measures to predicted amplitudes from anatomically-based scattering models; examining the application of sonar technologies to the enumeration and discrimination of acoustic targets; and acoustically quantifying size distributions, abundances, and behaviors of fish.

APPROACH

Acoustic backscatter models utilize digitized x-ray images of fish bodies and swimbladders to predict species-specific echo amplitudes as a function of acoustic wavelength, fish length, and fish aspect. Model predictions of scattering by individuals are used in computer simulations to estimate population abundance and are compared to laboratory and *in situ* field measurements.

WORK COMPLETED

Work continued on predicting backscatter amplitudes for several freshwater and marine fish species as a function of species, length, aspect angle, and acoustic wavelength. Predicted backscatter models were completed for alewife (*Alosa pseudoharengus*), rainbow smelt (*Osmerus mordax*), lake whitefish (*Coregonus hoyi*), Atlantic cod (*Gadus morhua*), brook trout (*Salvilinus fontinalis*), Namibian pilchard (*Sardinops Ocellatus*), and horse mackerel (*Trachurus trachurus capensis*). Predictions from backscatter models were compared to measures of American and New Zealand eels (*Anguilla* sp.), chinook and sockeye salmon (*Oncorhynchus* sp.), and lavnun (*Mirogrex terraesanctae*). Collaborations are underway to model and measure backscatter from Atlantic

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**
4. TITLE AND SUBTITLE **Modeling and Measuring Fish Backscatter at Multiple Frequencies**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Michigan,Cooperative Institute for Limnology and Ecosystem Research,NOAA Great Lakes Environmental Laboratory,Ann Arbor,MI,48109**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

herring (*Clupea harengus harengus*), paddlefish (*Polyodon spathula*), alewife (*Alosa pseudoharengus*), and capelin (*Mallotus villosus*).

Three international workshops or conference sessions were organized and conducted in the past year. The third Great Lakes Acoustic Workshop entitled, " Translation of acoustic data to fish abundance" attracted 30 participants from the Great Lakes and eastern US seaboard to the Cornell University Field Station in Bridgeport, New York. A special session entitled 'Theoretical and empirical innovations in fish and plankton acoustics' was held during the joint Acoustical Society of America/European Acoustics Association conference in Berlin during March. A Gulf of Maine/Georges Bank herring acoustics workshop was held at the Northeast Fisheries Science Center in Woods Hole during January.

Eight lectures were presented in conjunction with ongoing research and workshops during 1999. An invitational lecture summarizing the use and application of backscatter models was presented at a fisheries acoustics workshop hosted by Simrad in Seattle. Participation in the workshop resulted in an invitation to join the advisory board for the Scientific Assessment Technologies Laboratory (SATL) at the University in Toronto and to participate in sampling programs that integrate multibeam sonar and global positioning system (GPS) technologies. An invited lecture examining the use of theoretical scattering models for predicting target strength and choice of operating frequency was presented at the third Great Lakes Acoustic Workshop. Three presentations were made at the joint American and European Acoustical Society meeting held in Berlin. Overview lectures summarizing the use and application of backscatter models to fisheries acoustics was presented at the ICES FAST meeting in St. John's, Newfoundland, at the Alaska Fisheries Science Center in Seattle, Washington, at the Pacific Biological Station in Nanaimo, British Columbia, and at the Aquatic Ecology Laboratory at the Ohio State University in Columbus, Ohio.

RESULTS

The Kirchhoff Ray-Mode (KRM) model was extended to include fish species with multiple swimbladder chambers. To illustrate by example, backscattering cross-sectional areas from lavnun, a two chambered cyprinid, were comparable to those of single chambered species with similar swimbladder volumes (Fig. 1).

The KRM model predicts a non-monotonic increase in lavnun target strength with fish length. The shape of the predicted TS-length curve differs from that traditionally used to convert acoustic size to fish length. If fish are acoustically indistinguishable over large length ranges, the inability to segregate medium from large fish potentially influences quota allocation of a target species and *in situ* target strength data can not be used to obtain accurate length frequency distributions.

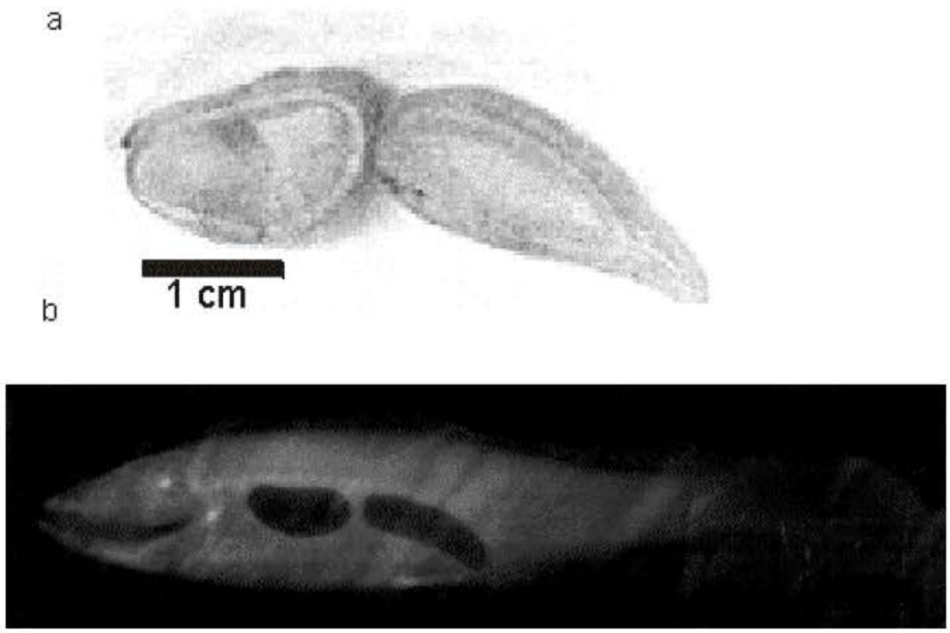

Figure 1. a) Lateral view of excised lavnun swimbladder. b) Lateral radiograph of lavnun showing anterior and posterior swimbladder chambers. Despite the obvious connection in the excised swimbladder, the connection between the two chambers is not visible in the radiograph.

Acoustic discrimination or identification of fish species using multi-frequency techniques is enhanced by maximizing echo amplitude differences among species-specific backscatter, optimizing backscatter curve features (e.g. minima and maxima amplitudes), and quantifying variability of intra-specific backscatter. Species-specific backscatter curves can be used *a priori* to optimize the number and choice of frequencies used during acoustic research surveys. Using ordinal ranking and a relational table, we found that separating and identifying species did not necessarily require more frequencies, but a judicious choice of frequencies (Fig. 2).

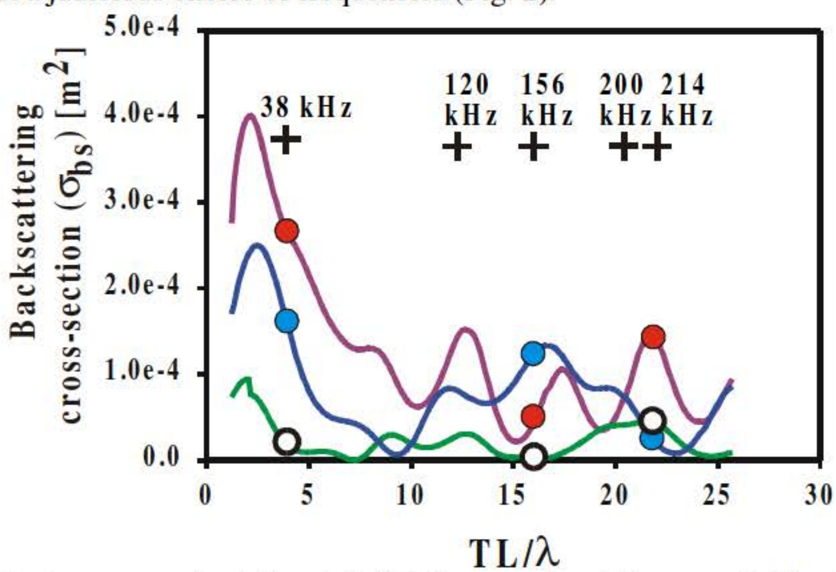

Figure 2. Scattering curves for lake whitefish (maroon), rainbow smelt (blue), and shad (green). Using ordinal ranking and a relational table (denoted by the vertical order of the red, blue, and white dots), each species can be identified at 38, 156, and 214 kHz . The three species are indistinguishable at 38, 120, and 200 kHz.

IMPACT/APPLICATIONS

Our research efforts continue to quantify the influence and relative importance of biological and physical factors on the magnitude and variability of acoustic backscatter from fish. Species-specific backscatter models verified using *in situ* echo amplitude measures provide powerful tools to investigate aural reflective properties of aquatic organisms. Predictions from backscatter models are used to examine techniques and resulting biases in acoustic population estimates. Understanding sources and variability of backscattered sound from fish aids the discrimination of biologic from anthropogenic acoustic targets.

TRANSITIONS

During a cruise in the Benguela Current region we extended the Kirchhoff-ray mode (KRM) model to include organism roll in backscatter estimates. This extension enables the calculation of 360^{o} pitch and 360^{o} roll of a single organism. Backscatter estimates can now be made for any sonar configuration at any incident angle. Estimates of acoustic backscatter of individual fish can now be compiled in probability distribution functions (PDF's) to characterize echo variability due to fish movement and transducer placement. This statistical approach is being extended to characterize backscatter variability from fish aggregations.

RELATED PROJECTS

Predicted echo amplitude PDF's from individual fish are being compared to those measured from fish aggregations. We are using KRM models to examine backscatter amplitude variability and behavior of fish aggregations.

PUBLICATIONS

Horne, J.K. and Jech, J.M. 1999. Multi-frequency estimates of fish abundance: constraints of rather high frequencies. ICES Journal of marine Science 56: 184-199.

Horne, J.K. 1999. Animal Groups in Three Dimensions. J.K. Parrish and W.M. Hamner (eds.) book review. Journal of Fish Biology 54: 1343-1344.

Horne, J.K. Book review of: Ecological Scale: Theory and Application. D.L. Peterson and V.T. Parker (eds.). Trends in Ecology and Evolution 14: 500.

Haro, A., Horne, J., Degan, D., Kulik, B. and Boubee, J. 1999. An Investigation of the Feasibility of Employing Hydroacoustic Monitoring as a Means to Detect the Presence and Movement of Large, Adult Eels (Genus *Anguilla*). CARFC Internal Report No. 99-01.

Misund, O.A., Buckle, W., Cloete, R., Coetzee, J., Dalen, J., Fossen, I., Haugland, E., Horne, J., Jech, M., Luyeye, N., Oechslin, G., Olsen, M., and Totland, B. 1999. An experimental survey of the abundance, spatial distribution, schooling behaviour and acoustic backscatter of the Namibian pilchard. Cruise Report 99-4, Dr. Fridtjof Nansen. 103 pp.

Rudstam, L, Horne, J., Fleischer, G. Report from the Great Lakes Acoustic Workshop III: Translation of acoustic data to fish abundance (and standardization of acoustic methods for the Great Lakes Region). Great Lakes Fishery Commission. 12 pp.

Jech, J.M. and Luo, J. 1999. Digital Echo Visualization and Information System (DEVIS) for processing spatially-explicit fisheries acoustic data. Fisheries Research (in press).

Walline, P.D., Tyler, J.A., Brandt, S.B., Ostrovsky, I. and Jech, J.M. 1999. Lavnun Abundance: How changes may affect Lake Kinneret's zooplankton. Advances in Limnology (in press).

Horne, J.K. Acoustic approaches to remote species identification. Fisheries Oceanography (accepted).

Jech, J.M. and J.K. Horne. Quantifying variability in acoustic estimates of fish abundance: effects of distribution, length, and acoustic size estimation. ICES Journal of marine Science (submitted).

Horne, J.K. Acoustic models and measures of American eels: influences of anatomy, behavior, and frequency. Fisheries Bulletin (submitted).

PRESENTATIONS

Horne, J.K. 1998. Acoustic models, measures, and simulations of fish in the Great Lakes. Invited lecture. Simrad Fisheries Research, Freshwater Acoustic Meeting. Seattle, Washington.

Horne, J.K. 1999. Theoretical scattering models for predicting target strength and the choice of operating frequency: applications to alewife and smelt in the Great Lakes. Invited lecture. Great Lakes Acoustic Workshop III. Cornell Biological Field Station, Bridgeport, New York.

Horne, J.K. 1999. Acoustic approaches to remote species identification. 137^{th} Meeting of the Acoustical Society of America. Berlin, Germany.

Horne, J.K., Jech, J.M. and Walline, P.D. 1999. Comparing predictions from backscatter models to *in situ* measurements of a dual-chamber, swimbladdered fish. 137^{th} Meeting of the Acoustical Society of America. Berlin, Germany.

Jech, J.M. and Horne, J.K. 1999. Multi-frequency measures and models of Lake whitefish (*Coregonus clupeaformis*) backscatter from Lake Michigan. 137^{th} Meeting of the Acoustical Society of America. Berlin, Germany.

Horne, J.K. and Jech, J.M. 1999. Quantifying variability in fish backscatter: Integrating theory and empiricism. ICES Fisheries Acoustics Science and Technology Working Group annual meeting. St. John's, Newfoundland, Canada.

Horne, J.K. 1999. Quantifying distributions and dynamics of aquatic organisms. Invited lecture. Alaska Fisheries Science Center, Seattle, Washington. Pacific Biological Station, Nanaimo, British Columbia.

Horne, J.K. 1999. An overview of acoustic backscatter models and applications to fisheries resource assessment. Invited lecture. Aquatic Ecology Laboratory, The Ohio State University, Columbus, Ohio.

WORKSHOPS AND CONFERENCE SESSIONS ORGANIZED

Great Lakes Acoustic Workshop III: Acoustic size and assessment. 1999. Great Lakes Fisheries Commission, Cornell University Field Station, Bridgeport, NY.

Theoretical and empirical innovations in fish and plankton acoustics. 1999. Joint American Society of Acoustics and European Acoustics Association, Berlin, Germany.

Gulf of Maine Herring Acoustics Workshop. 1999. NOAA/NMFS/NEFSC Woods Hole, MA.